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MACHINE CASTING OF FERROUS ALLOYS

SEPTEMBER 1975

G. D. CHANDLEY AND GARY SCHOLL
HITCHINER MANUFACTURING CO., INC.
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MILFORD, N.H. 03055

Interim Report

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Due to the lack of economic permanent die materials for use in Hipocasting ferrous alloys, three innovative approaches for creating a mold cavity for use in machine casting of ferrous alloys were explored. They were: use of liquid metal cooling of a thin walled die, use of a porous die, vacuum coated with dry ceramic and use of a membrane to vacuum from a disposable

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) mold. Vacuum forming a disposable mold appears to be the most promising method for machine casting of ferrous alloys.

FOREWORD

This report covers work done in the period 1 February 1975 - 30 June 1975, under the general title "Machine Casting of Ferrous Alloys". The work is sponsored by the Defense Advanced Research Projects Agency under ARPA Order No. 2267, Program Code No. 4D10. The work was carried out at the Hitchiner Manufacturing Company, Inc., Elm Street, Milford, N.H. 03055, by the principal investigators, G. D. Chandley and Gary Scholl, (Tel: (603)673-1100). The work was accomplished under Contract No. DAAG46-73-C-0112 with Dr. E. Wright/ Mr. Frank Quigley at Army Materials and Mechanics Research Center as the program technical monitor.

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I. INTRODUCTION AND BACKGROUND

During the past thirty months, Hitchiner Manufacturing Company, Inc. has been actively engaged in the development of an economically feasible process to machine cast ferrous alloys. Several creative methods have evolved with varying degrees of success. The Hipocast process, see Figure 1, developed specifically for this program, continues to be the most encouraging of all machine casting processes presented to date. The program had initially been directed primarily toward the optimization of the casting system, assuming that, when this had been accomplished, conventional approaches to economic die life would fulfill the overall objectives. In keeping with this approach, the use of permanent molds of all likely materials have been investigated; the concept of a composite die which incorporates a second metal in the liquid phase to facilitate heat transfer, has also been pursued (see Figure 2). That operating assumption is now seen to be erroneous. In the casting of ferrous alloys, economic feasibility must begin with an economic mold system. Recent efforts have therefore been solely devoted to the development of a mold system which will satisfy the following requirements:

1) Ability to withstand $3000^{o}F$.
2) Ability to react to dimensional changes of the casting.
3) Freedom from chemical reactions which may cause surface and gas defects.
4) The ability to maintain surface and dimensional integrity.
5) The contribution of the die system cost to each casting should not exceed 25 cents for an 8 oz. part.

II. NEW DIE SYSTEMS

A. <u>Aspi-cast system</u>

An aspirating die system has been conceived and implemented in several stages for investigation. Porous metal molds were fabricated by a powdered metals process. These inserts (containing the casting cavity) were placed in specially designed fixtures which created a vacuum behind the porous mold. The pressure differential across the mold to atmosphere was then used to maintain a thin coating of refractory particles at the exposed surface of the porous insert. The system relies on the refractory particles to protect the die materials from intimate exposure to the casting environment and allows for easy expulsion of the coating and casting by pressurizing the mold.

Initial tests were setup to establish functional relationships which would later be used to predict and control the nature of surface coatings. Here, it became immediately evident that a material's "porosity", as rated by the manufacturer, was related to an industry standard "bubble test" and, although indicative of the material's filtering capabilities, did not necessarily reflect the size of the exposed pores. To avoid confusion, pore size, as used in our work and this report, refer to the average diameter of pores measured at the surface. Table 1 in the appendix summarizes the physical properties of the porous die materials tested. Using the apparatus depicted in Figure 3, preliminary data was gathered using the following procedures:

1) Refractory sands of a single sieve size were bulk loaded onto the mold surface.
2) The vacuum pressure behind the mold was increased to 30 inches of mercury and the mold was rotated 180° (upside down).

3) The vacuum pressure was then slowly decreased until only a thin layer of sand remained attached to the mold face.

The transition between bulk and lamellar retention was dramatic at well defined pressures. That transition pressure was found to be strongly related to the ratio of particle size to pore size and the function appears in Figure 4. The sand particles retained after the lamellar transition were then weighed and an estimated surface coverage was computed from geometric considerations. The surface area coverage function is linearly proportional to the ratio of retained weight to particle size, and is influenced somewhat by a size factor. An illustration of the function appears in Figure 5.

Several casting cycles were accomplished using surface coverages of approximately 40 and 250%. Failure resulted in all tests after a small number of castings (i.e. less than 5). Tests using a porous bronze material failed when a substance (probably tin) melted, migrated and resolidified closing porous passages. A micrograph of this phenomenon appears in Figure 6. Porous inserts of 316 stainless steel failed when the surface pores became clogged with an oxide of unknown origin. An optical photograph of this failure mode also appears in Figure 6.

B. Hypo-V Process

Concurrent with the investigation of the Aspi-cast die system, the evaluation of possible advantages of a mold system which totally creates the cavity in unbonded sand using a light vacuum and a low permeability membrane was begun. The sequence of events can best be described by the schematic illustrations in Figure 7. Essentially, the process begins by vacuum forming a thin membrane to a porous pattern board. This board and membrane is then placed against a hollow die, which is subsequently backfilled with sand. Finally the die is evacuated of remaining air and atmospheric pressure is returned to the pattern board. This effectively transfers the membrane, still retaining the pattern surface geometry, to the die.

Preliminary tests were accomplished using a polyethylene film stretched and vacuum formed over a pattern which was mounted to a porous metal plate. The first castings to be made using this mold system and the Hipocast machine appear in Figure 8. The surface texture which appears here was improved upon slightly by selecting finer sands for the mold and by decreasing the vacuum pressure in the mold to reduce penetration. It now appears, however, that to achieve the desired surface roughness (100-250 micro-inch) the dies must be altered to cause pressure molding of fine sand grains at the membrane surface.

C. Augmented Hypo-V Process

An improved system is currently being pursued which incorporates a porous ceramic coating between the membrane and the sand mold. The ceramic is spray deposited in an ethyl silicate and flour slurry which is rapidly gelled chemically. The advantages of such a mold system are numerous and excellent surface and geometric integrity can be achieved. Although several steps are required to complete the casting cycle, the system appears to lend itself to full automation and that the short casting cycle times associated with "machine casting" will be achieved. The ceramic coating, although permeable, will support the mold face without the cavity forming membrane. This then gives rise to the possibility of a reuseable membrane. Further, with the membrane removed, we have essentially a low cost, permeable mold which is highly suitable for vacuum ingestion of high temperature liquid or semi liquid metals. The sequence of events for such a casting cycle are schematically represented in Figure 9.

The material selection for the low permeability membrane is considered an important aspect in the development of this process. Early tests were conducted using readily available polyethylene films marketed as food packaging wraps (e.g. Saran Wrap, Miracle Wrap, Glad Wrap, and others). Of these items Glad Wrap yielded superior results when formed over small parts which did not have complex shapes. These materials had an added advantage in that once transferred to the mold, they could be easily ignited and burned off while curing the ceramic coating. At this time in the program a decision was made, selecting a suspension type bomb lug (see Figure 10) for our standard machine casting part. This part is to be cast in 4340 low alloy steel and has a market potential of 5 million parts per year at a price of $2 each. The part is presently being made as a machined forging and can not be priced at this level as an investment casting. The complex geometry of this part could not be transferred using the polyethylene films and an in depth materials search was initiated.

Although the overall elongation of the parting membrane for the bomb lug part was around 200%, the complex geometry of several selected areas requires elongation which may exceed 800%. This led to an investigation of elastomers. An important criteria for elastomers, in light of their high costs, was reuseability. This has come to mean

1) Alkali and Acid resistance
2) General resistance to chemical attack
3) Low porosity
4) Availability in thin sheet form
5) Heat resistance
6) High elasticity

Several natural and synthetic rubbers have been tested. The fluorocarbon compounds of Kel-F and Viton were not available in the thin sections required, the natural and silicone rubbers frequently did not satisfactorily resist chemical and mechanical attack by the ceramic. Reasonable success has been achieved using an ablative teflon mold release to protect the natural rubbers. Neoprene rubbers and a cast teflon film are still under investigation.

Additional plastic films have also been investigated. Here the low cost frequently makes the films economic on a non-reuseable basis. In many cases this means that the only necessary criteria is elongation. However, this one criteria has excluded all films to date. Although many of these films are thermoplastic, the controlled addition of heat creates other problem areas in the ultimate process automation and this technique has not as yet produced satisfactory results.

Several other approaches to the release membrane problem are also under consideration. For example, casting of the pattern geometry in a flexible material (such as rubber) for evaluation.

The ceramic coating is applied by spraying a slurry onto the formed release membrane. The slurry consists of zircon flours suspended in a partially hydrolyzed ethylsilicate binder. These materials were readily available and are used daily in Hitchiner's shell building facilities in the production of investment casting shell molds. Several minor alterations of the slurries are necessary, however, to adjust the gelation time and the viscosity for compatibility with the process requirements and spray apparatus. The typical slurry formation and physical data appear in table 2 in the appendix. Numerous problem areas have arisen in conjunction with the application of the ceramic coating. The majority of these have been solved on a cut and try basis. At this time the best coating methods seem to incorporate the following criteria:

1) The spray device should have a gravity feed and the slurry must not be permitted to stand in the nozzle section.
2) Agitation of the slurry can not be discontinued for periods in excess of 1 minute.
3) The application of granular sands AFS No. 100 by sand blast, results in a superior coating with respect to uniformity and strength.

4) The optimum method for applying the coating appears to be by alternating between the gelling solution and the slurry as opposed to simultaneous sprays.

Prior to casting, the alcohol solvent in the ceramic coating is ignited by a low temperature flame. This also insures completion of the gelling reaction and drives off any remaining moisture. The remaining coating contains numerous microscopic cracks but these are not readily visible to the unaided eye nor are they visible on the casting.

Several bomb lug castings using this mold system and the hipocast machine have been made. The results are very encouraging and in some respects are superior to the quality achieved using metallic molds. A photograph of the first of these parts appears in Figure 11.

III. CONCLUSIONS

The necessity to control mold amortization costs in a machine casting process for ferrous alloys excludes the use of conventional metallic dies when casting with liquid metal. Several regenerating refractory mold systems have been examined; one of these methods may ultimately result in an economically feasible mold system.

The hypo-V process has the inherent advantage of its simplicity and accompanying low costs. The membrane requirements, however, have not yet been met for complex geometries. The augmented hypo-V process yields superior surface integrity and is easily adapted to vacuum filling. On the other hand, this process requires more sophisticated control and automation procedures, which along with increased material costs, may exceed our amortization objectives. The Aspi-cast system has numerous cost advantages but the technical feasibility remains in question.

IV. RECOMMENDATIONS FOR FUTURE WORK

Vacuum mold systems are being actively tested. The coming months should produce conclusive results in at least one of these methods. The concept of vacuum injecting molten and semi-molten steel into these molds will become a reality in the coming weeks. It is hoped that this concept can be incorporated with any of these vacuum die systems and will alleviate some problem areas unique to the hipocast process.

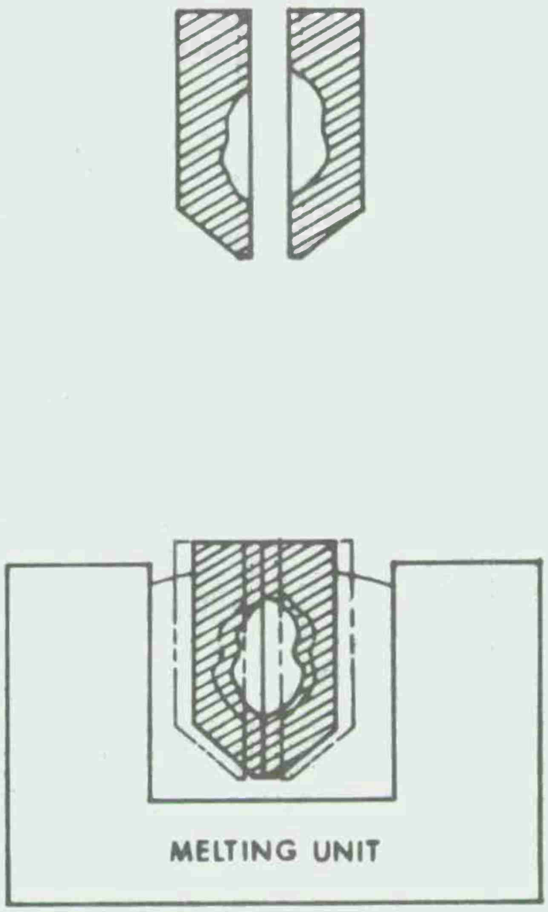


Figure 1. Schematic of Hipocast Process

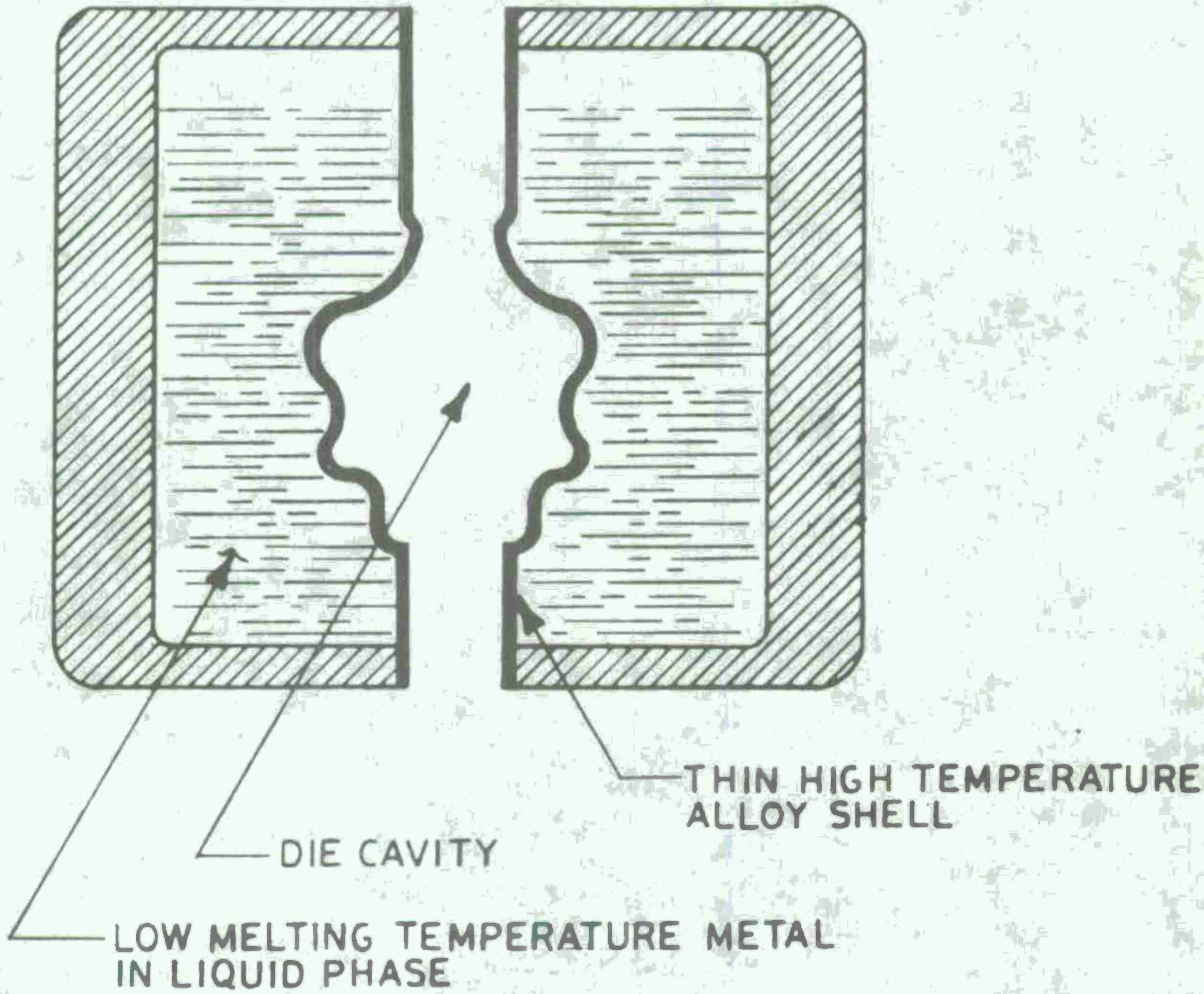


Figure 2. Schematic of Composite Die.

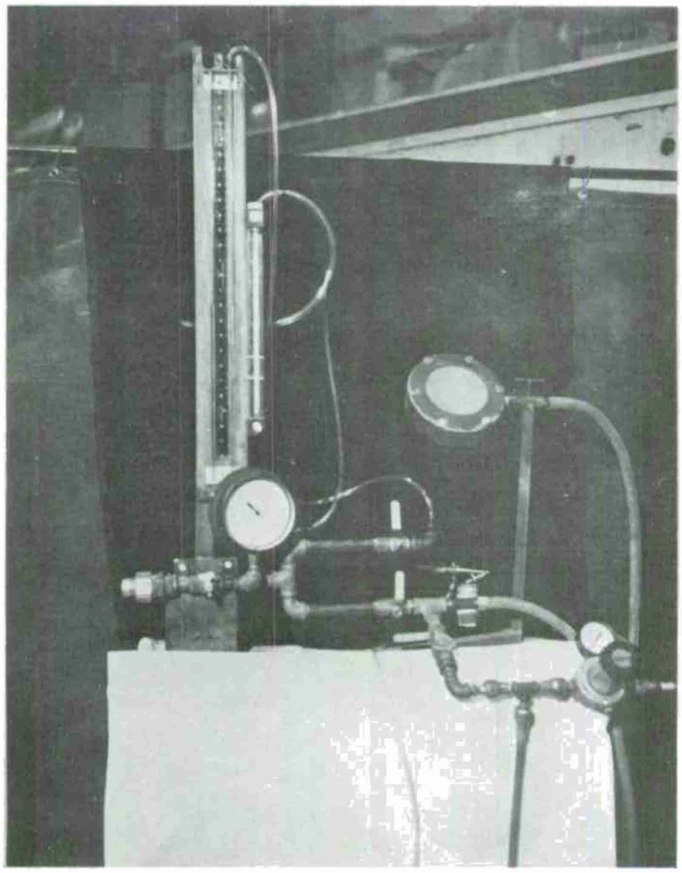


Figure 3. Test Apparatus for Aspi-Cast System.

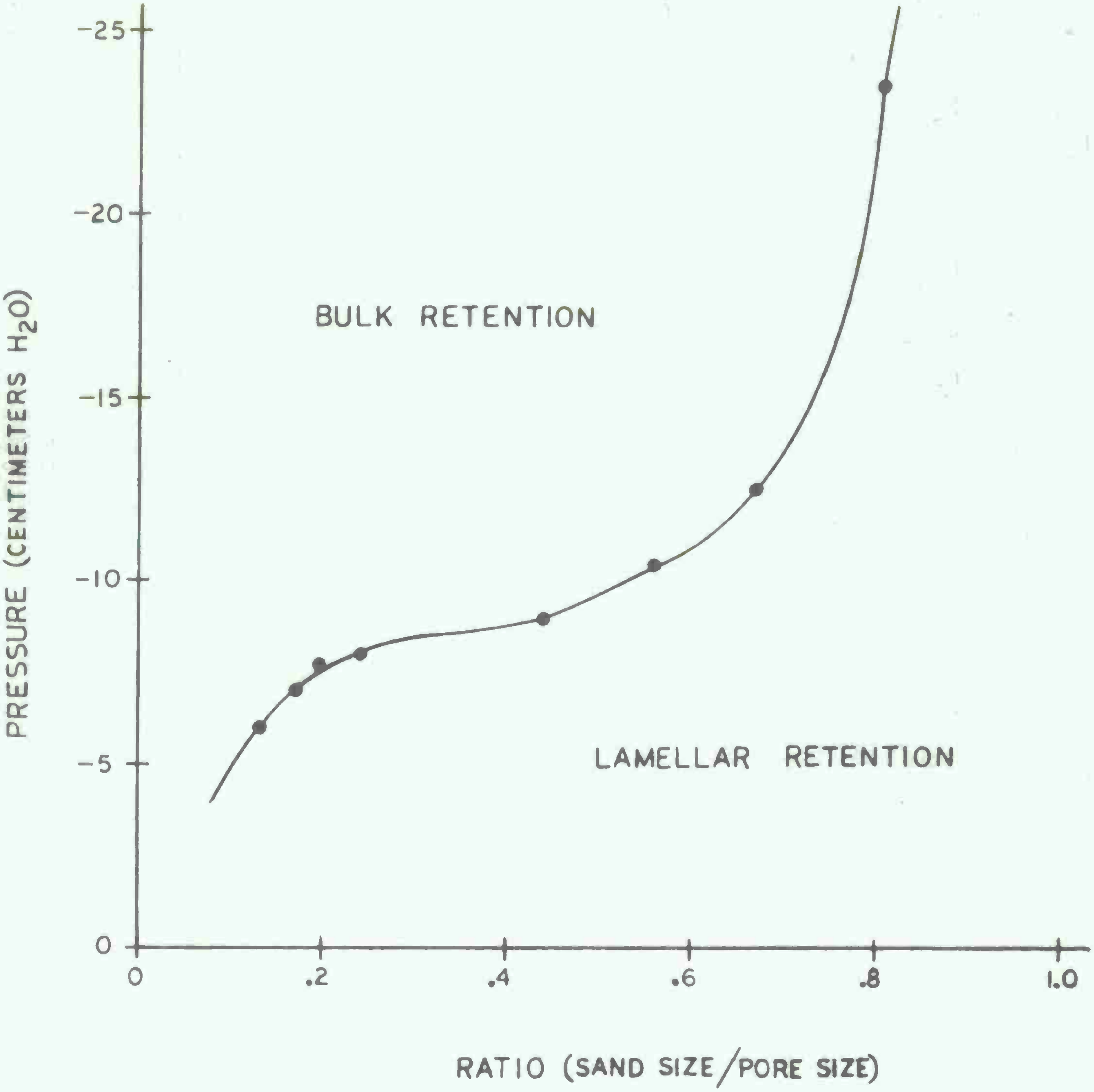


Figure 4. Pressure function for transition of sand retention mode.

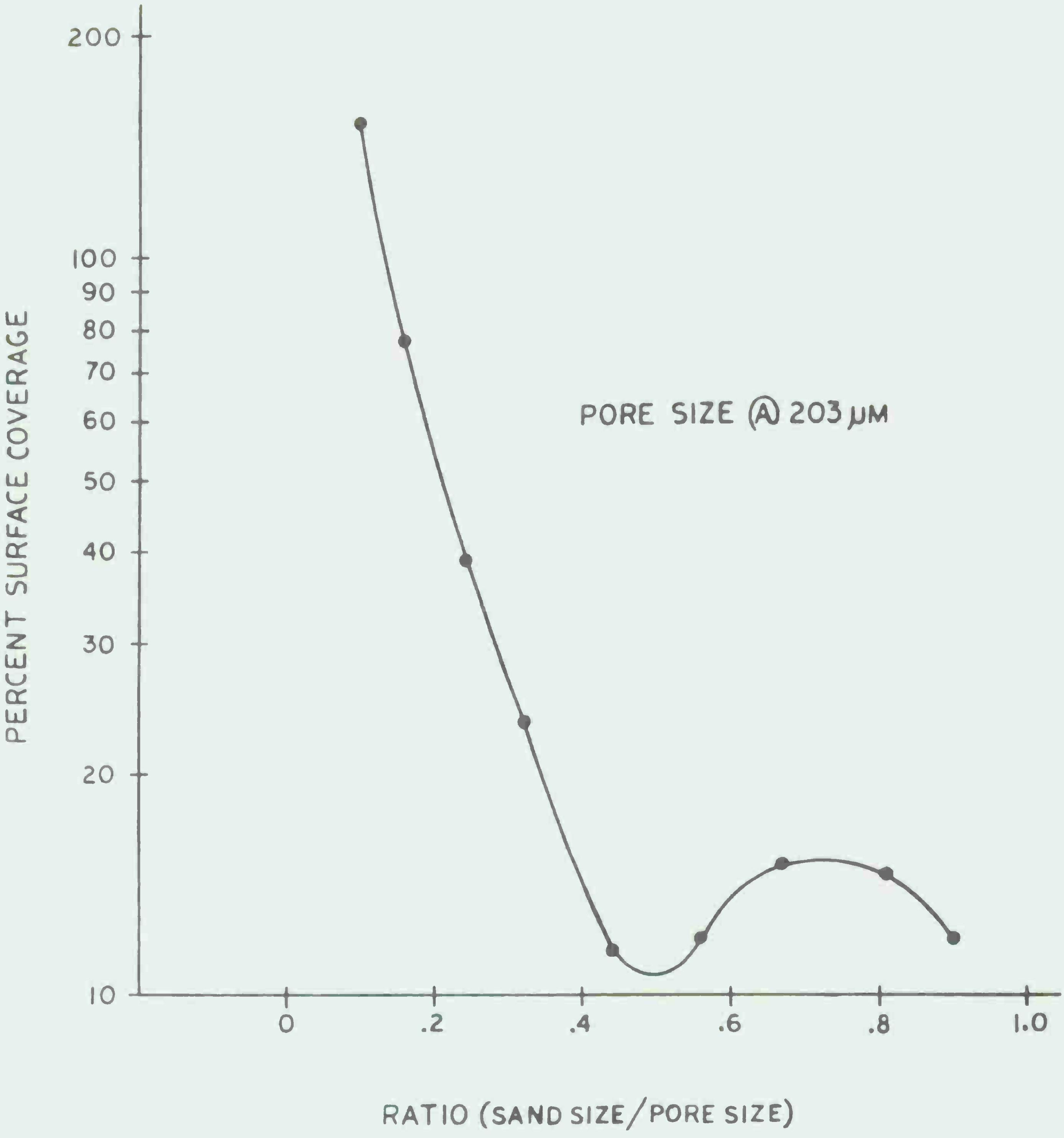
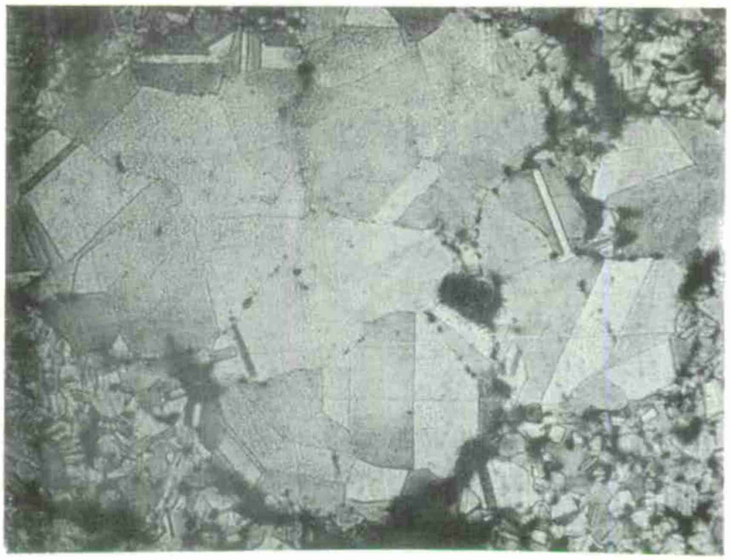
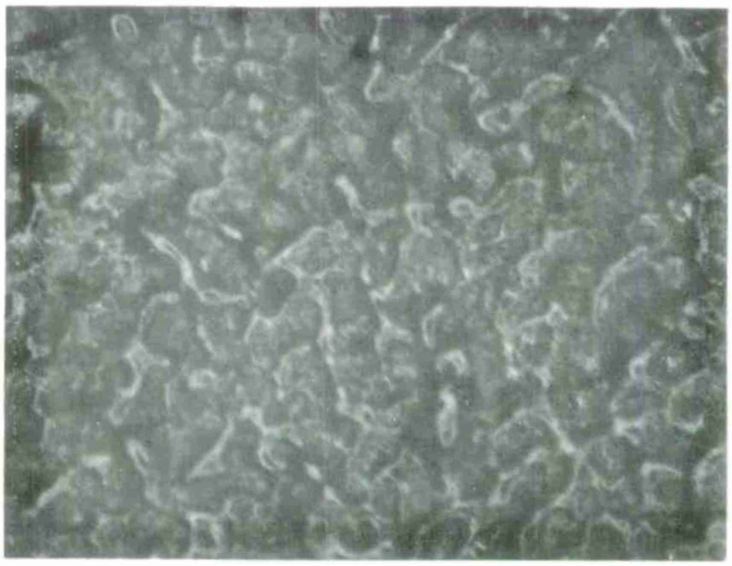


Figure 5. Functional relationship of surface area coverage.



(a) Interior section of bronze die (200x)



(b) Surface of 316 stainless steel die after 5 castings (56x)

Figure 6. Photographs of porous metal dies which failed in service.

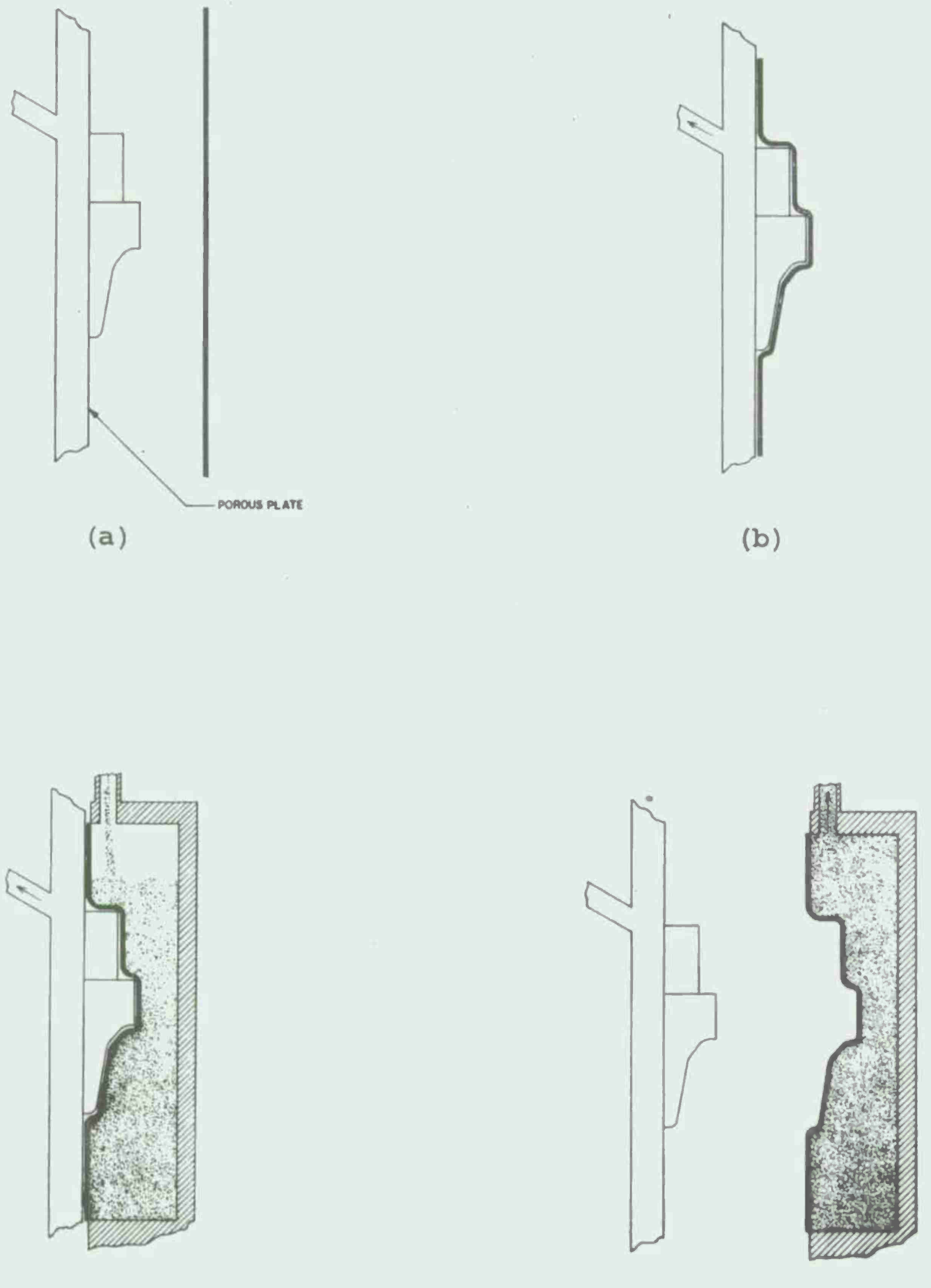
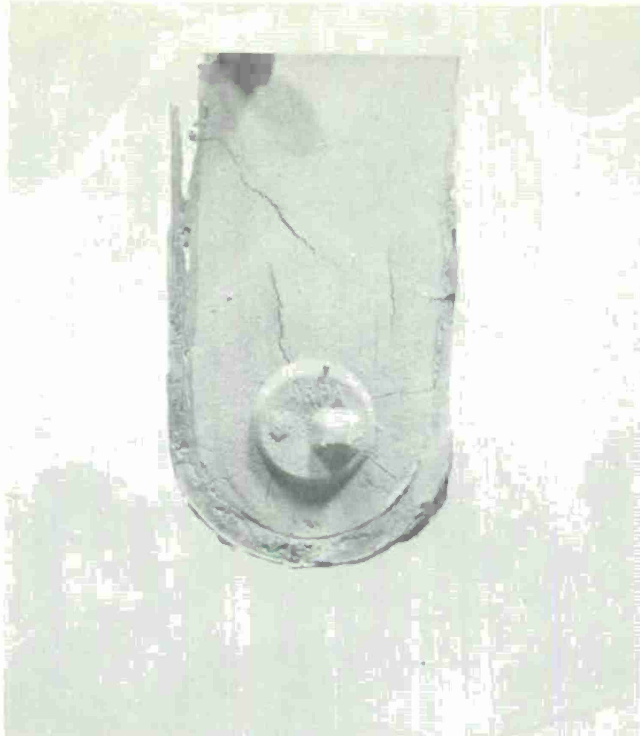


Figure 7. Sequence of mold preparation for Hypo-V Process.



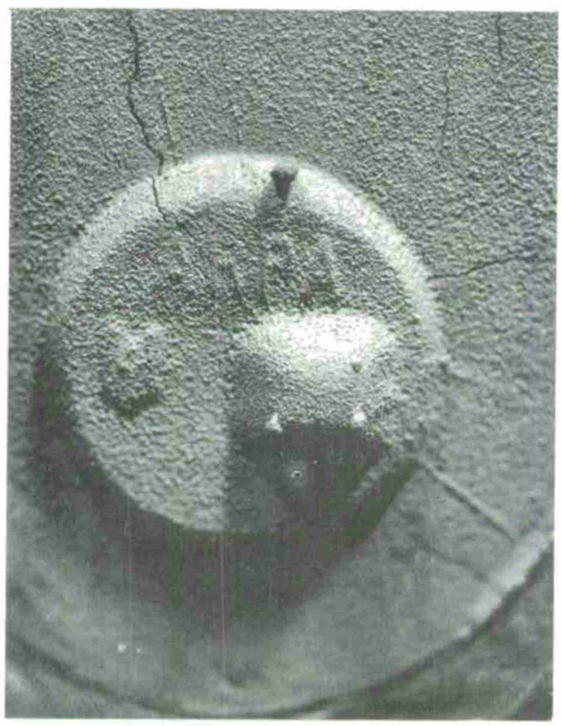


Figure 8. Photographs of first Hypo-V casting.

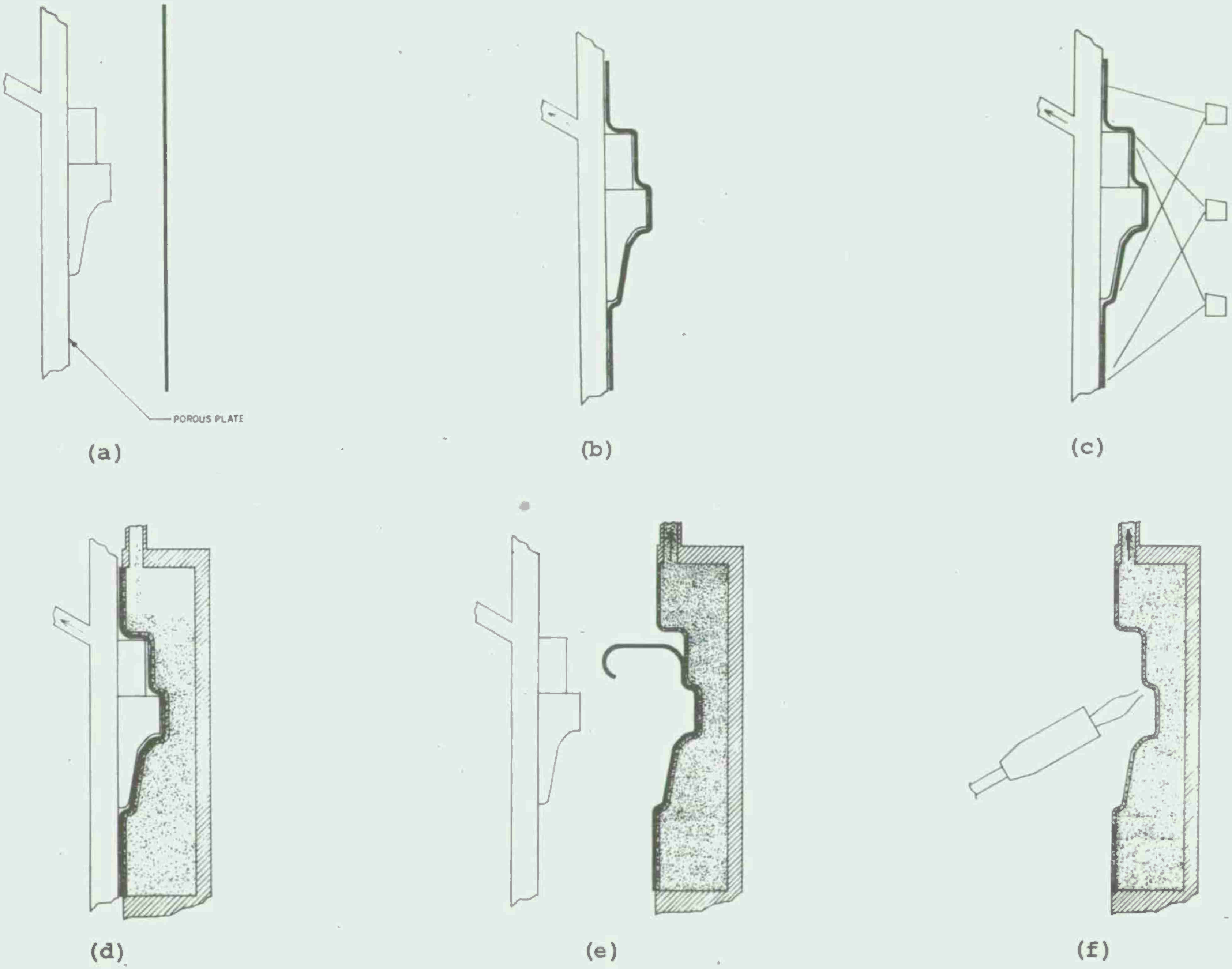


Figure 9. Sequence of mold preparation for augmented Hypo-V Process.

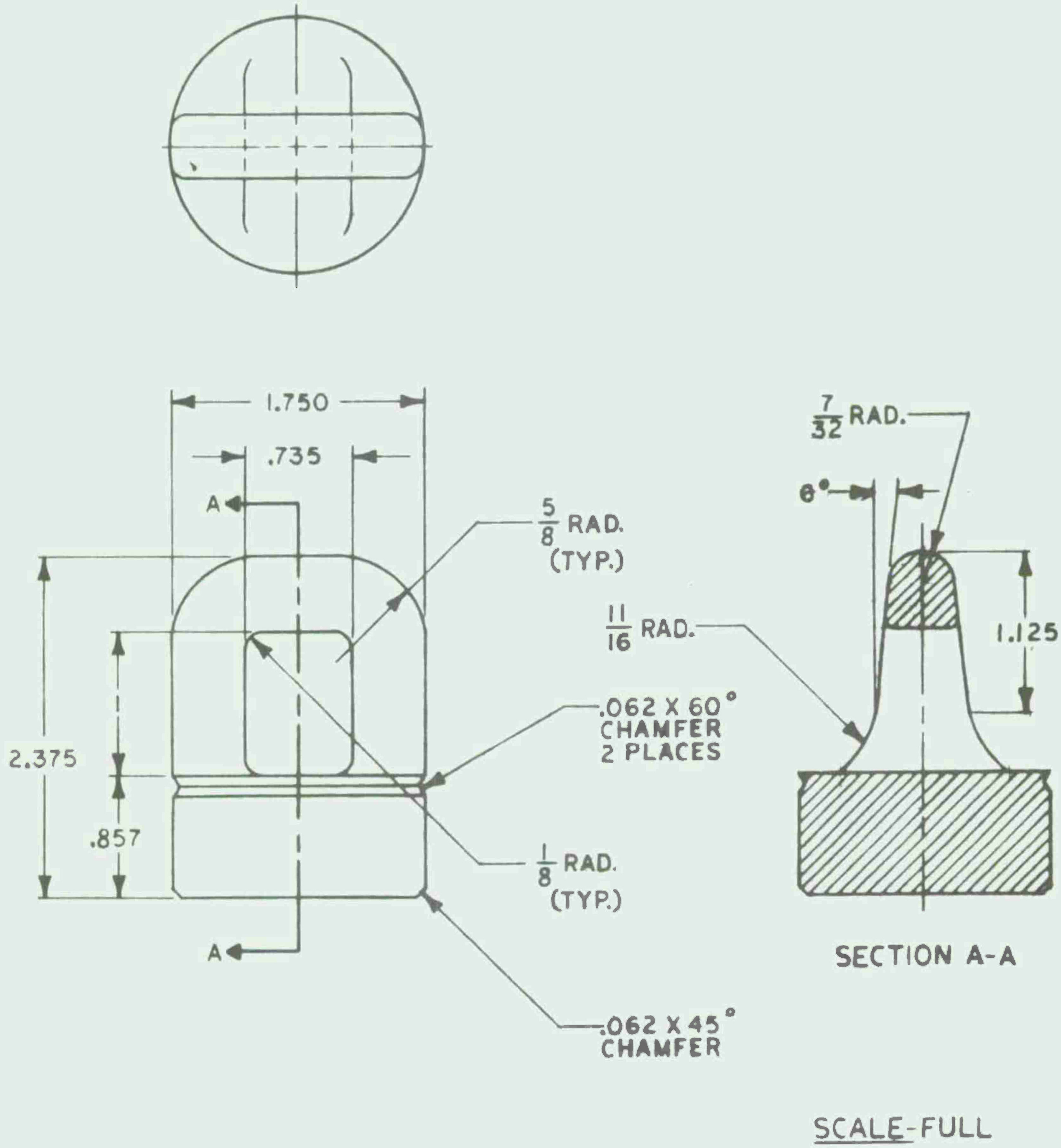


Figure 10. Drawing of suspension Bomb Lug.

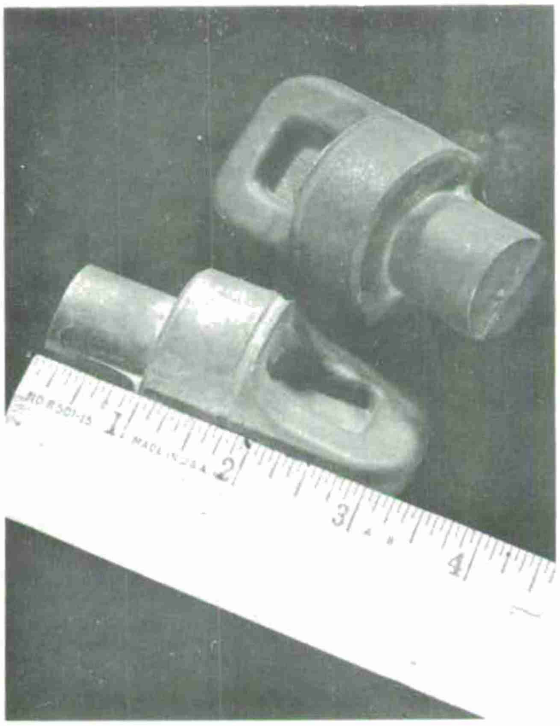


Figure 11. Photo of first bomb lugs made by the augmented Hipocast Process.

TABLE 1. Physical Properties of 316 Stainless Steel Porous Metal Dies

Porosity Micron	Particle Size Micron	Density %	Flow Conductance $\frac{scm^3/s/cm^2}{g/cm^2}$
5	165	50	.994
10	240	47	1.92
20	450	48	3.60
40	725	41	21.6

TABLE 2. Composition and Physical Properties of Slurry

Composition by Weight

Ethyl Silicate 40	15%
Isopropyl Alcohol (Anhydrous)	6%
Refractory flours (2-6 micron dia.)	79%

Physical Properties

Specific Gravity	1.65
pH	2
Gel Time for 75cc Slurry with 6cc 2.5% $(NH_4)_2CO_3$ solution	100 sec
Viscosity Brookfield No. 3 spindle @ 100 RPM	115 cp

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G. D. Chandley
Gary Scholl
Hitchiner Manufacturing Co., Inc.
Milford, N.H. 03055

Technical Note: AMMRC CTR 75-18, September 1975
Contract DAAG46-73-C-0112
AMCMS Code: 691000.21.66024
Interim Report, 1 February 1975 - 30 June 1975

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Key Words

Solidification
Die Casting

Due to the lack of economic permanent die materials for use in Hipocasting ferrous alloys, three innovative approaches for creating a mold cavity for use in machine casting of ferrous alloys were explored. They were: use of liquid metal cooling of a thin walled die, use of a porous die, vacuum coated with dry ceramic and use of a membrane to vacuum from a disposable mold. Vacuum forming a disposable mold appears to be the most promising method of machine casting of ferrous alloys.

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